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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Provides procedures for using high-speed radiographic equipment to obtain shadowgraphs or radiographs showing projectile performance in-bore, at the muzzle, in flight or when impacting upon a target.

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FLASH RADIOGRAPHY IN BALLISTIC TESTING

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1. SCOPE. This TOP provides procedures for testing the ability of high-speed radiographic equipment to obtain shadowgraphs or radiographs showing projectile performance in-bore, at the muzzle, in-flight, or when striking a target.

2. FACILITIES AND INSTRUMENTATION. Installation and operation of X-ray facilities shall be approved by the I/FOA Radiation Protection Officer (RPO) and the Radiation Control Committee.

2.1 Facilities.

<u>ITEM</u>	<u>REQUIREMENTS</u>
Flash X-ray unit (see fig. 1 and App A)	Refer to paragraph 3.1.
Trigger circuit	Provide a triggering signal for pulsing the X-ray unit at the appropriate time (see para 3.2.4)
Intensifying screens	Mylar sheets coated with a chemical such as calcium tungstate which fluoresces immediately after absorbing X-rays and enhances the ability of the X-rays to produce usable information on film

*This TOP supersedes TOP 4-2-825 dated 8 June 1978, AD No. A057390.

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<u>ITEM (cont'd)</u>	<u>REQUIREMENTS (cont'd)</u>
X-ray film	Standard medical, w/double-sided emulsion
Cassettes (metal/plastic holders for cardboard film holders)	As needed to protect the film holders and screens from blast and fragmentation
Operational shields	Standard and specially modified bomb-proofs to protect equipment from blast and fragments

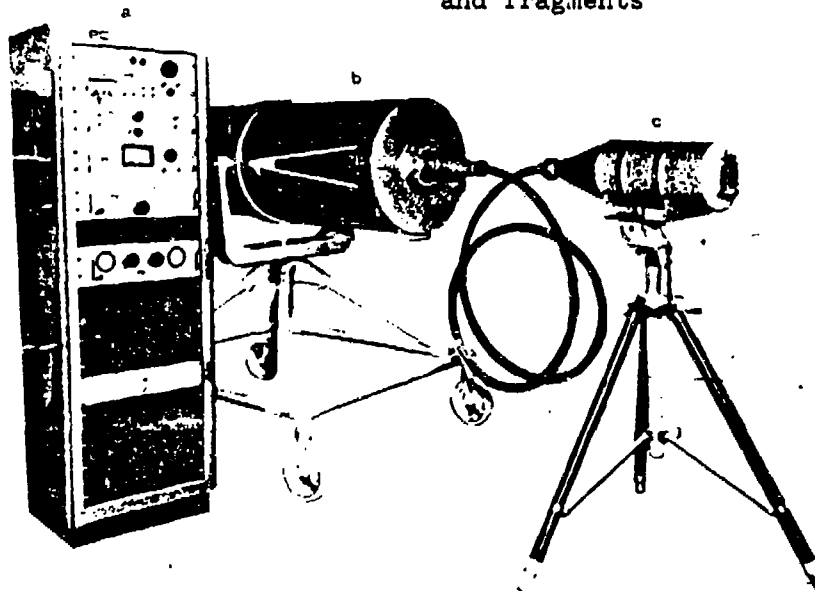


Figure 1. X-ray equipment for one-channel, 600-kV flash radiographs including:
 a. Control panel (high voltage power supply, delay generator, trigger amplifier, freon and nitrogen gas regulators)
 b. Pulser
 c. Remote tube head.

2.2 Instrumentation.

<u>DEVICE FOR MEASURING:</u>	<u>PERMISSIBLE ERROR OF MEASUREMENT:*</u>
X-ray dosage (e.g., direct-reading dosimeters)	10% of full-scale reading for 0-200 mrad range
Personnel exposure to X-rays (e.g., film badges)	NA
Time of test event and pulse (e.g., pulse-event timer)	+1 count, -0 count (least significant digit)

*The permissible error of measurement for instrumentation is the two-sigma value for a normal distribution; thus the stated errors should not be exceeded in more than one measurement of 20.

3. REQUIRED TEST CONDITIONS.

3.1 Planning.

a. Review the ballistic data requirements and the characteristics of the test item. Such information as shape of projectile, location of exterior components, configuration of interior components, damage to target or simply a general view of a projectile at a particular location may be required.

b. Select a flash X-ray unit of the proper voltage to obtain the required ballistic data based on the material mass of the test object and the source-to-object distance necessary to avoid potential damage to X-ray equipment. It is best to try to maintain a 5-to-1 ratio with the source-to-object and object-to-film distances. Establish a source of 120 volts AC power with minimum 15-amp service, using either a generator or hard wire hookup. The following are typical examples of units currently being employed:

(1) 150 and 180 kV - radiographs/shadowgraphs of fragment mass and position in lethality studies. These systems are also useful in providing pitch and yaw measurements for projectiles of various calibers, through the use of orthogonal pairs.

(2) 300, 600, and 1000 kV - radiographs of test objects when penetration of the object is necessary to assess ballistic performance, or a large source-to-object distance is necessary to prevent equipment damage.

(3) 2.3 MeV - radiographs of projectile in-bore or of test objects when penetration of the object is necessary to assess ballistic performance, and for recording large-scale ballistic events.

(4) Multi-channel units are required when more than a single flash radiograph of a ballistic event is needed. Examples of this requirement are the need for views at two or three distances in front of the gun muzzle or two sets of orthogonally paired views of fragments coming off the rear of a target plate for determination of fragment mass and position in lethality studies. A single-channel unit can be built up to a multi-channel capability by adding more pulsed, delay generators, trigger amplifiers, and X-ray tubes (plus cables and tube heads when remote operation is required).

c. Determine the optimum operating parameters for obtaining the desired X-ray penetration (e.g., charging voltage, tube-to-object and object-to-film distances) from records of past radiographic examinations or by making static radiographs of the test item.

d. Establish test sites for the X-ray equipment to produce the required radiograph or shadowgraph. The setup will depend to a great extent on the following:

- (1) Number of views necessary and spatial arrangement of views.
- (2) Expected velocity and direction of the test object.
- (3) Damage potential to the X-ray equipment.

e. Prepare a test operations checklist using Appendix B as a guide and adding specifics for the test item and situation.

f. Design data collection sheets for the particular radiographic examination covering such data requirements as listed in paragraphs 3.3 and 5.

3.2 Equipment Setup.

3.2.1 X-ray Equipment.

a. Locate the X-ray equipment at the firing site in accordance with requirements determined during planning. Use standard bombproofs or other arrangements of armor plate to protect high voltage pulse-forming equipment and controls from blast or fragments as appropriate. Figure 2 shows a typical setup. A special armor-plated X-ray trailer may also be used.

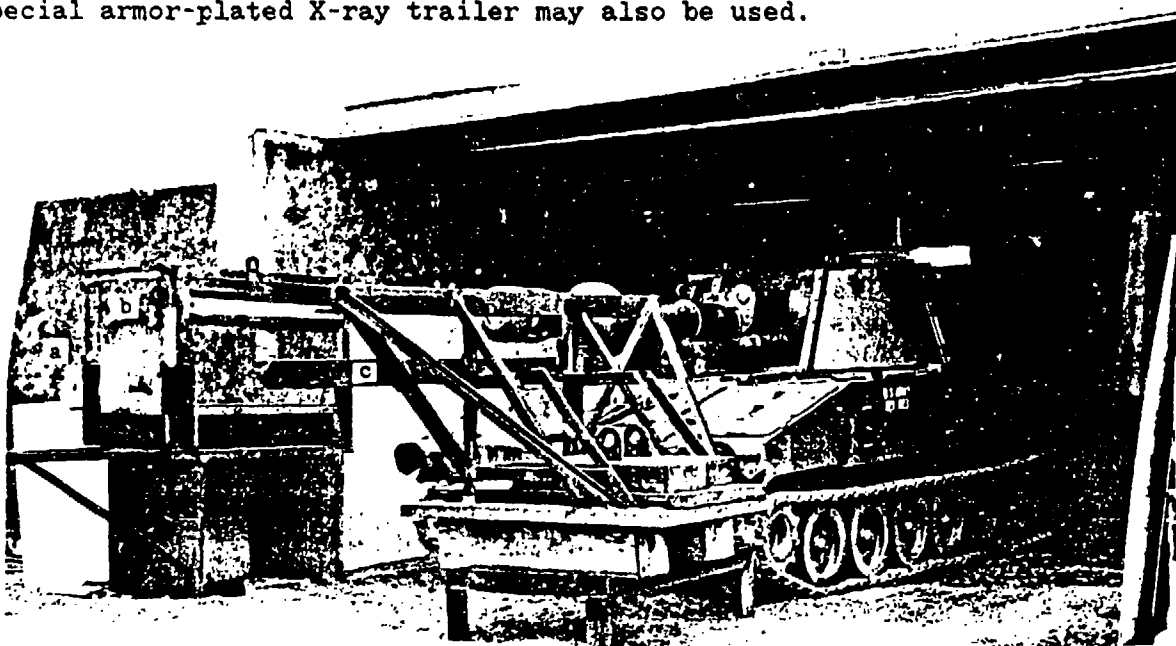


Figure 2. Setup for flash radiography at muzzle of 155-mm gun showing armor protection and equipment arrangement: a. Armor plate (protects pulser) b. Small bombproof in which two tube heads are mounted (polyethylene window is in front of tube heads) c. Metal stand for cassette.

b. Install the pulser or remote tube head containing the X-ray tube in a specially modified bombproof (b in fig. 2) with a slit opening covered by a sheet of 1/2 in.-thick linear high density polyethylene in front of the X-ray tube head. Under severe test conditions, the coaxial cable that connects the pulser to the remote tube head may also have to be protected by armor plate. In multi-channel setups, lead shielding is often required between adjacent X-ray tubes to prevent "flashover" on the X-ray film. The bombproofs and shields used are typically moved to and from test sites by mobile truck cranes and tractor trailers.

3.2.2 Film and Screens. Use of high speed screen-type double-emulsion film is recommended for flash radiography.

a. Place a fluorescent chemical-intensifying screen in contact with each side of the film, and enclose the film and screens in a regular cardboard X-ray film holder. The intense, short pulses of X-ray energy have little effect on the film unless the intensifying screens are used. Fluorescence of the chemical on these screens produces the radiograph on the film.

b. When protection against blast is required, insert the film holder into a metal/plastic cassette between sheets of felt or foam rubber which provide

pressure against the film and screens and serve as a shock absorber when the ballistic event occurs.

c. Position the film holder or cassette behind the test object (or its expected location) and directly in front of the X-ray tube(s) using a suitable stand or structure capable of withstanding the shock of the blast when appropriate. The film should be placed as near as possible to the line of trajectory of the test object for maximum clarity of the radiographic image but far enough away to avoid possible damage from blast and fragments. When using film holders, provide some means to keep the film in contact with the intensifying screens such as placing the film holder between sheets of felt and plywood. When metal cassettes are used, do not fasten the cassettes firmly in place. Permitting the blast from the explosion to move the cassettes increases their ability to resist blast damage. Every effort should be taken to install horizontal and vertical fiducial lines on the X-ray image by using wire, etc. The X-ray cassette should be such that the entire projectile can be covered on the film. This aids in establishing projectile deformation, bend, etc. Since coverage of a projectile on several films is very cumbersome, coverage on one film is preferred.

d. Place all identification numbers/letters and lead or wire reference markers on the side of the X-ray film holder facing the X-ray tube head locations. This will allow the numbers/markers to be imprinted on the film. If measurements are to be taken from the film, it is necessary to provide fiducial wires to properly locate film holders and provide a horizontal level wire, preferably representing the line of fire. These marks should be located by geodetic measurements personnel.

3.2.3 Trigger Circuit. Select and install a trigger circuit to suit the particular ballistic study (i.e., projectile performance in-bore, at the muzzle, in-flight or after impact). Triggering is usually accomplished from a single trigger with successive pulse intervals controlled by delay generator settings for additional channels. Separate triggers may be used for additional channels; if this is the case, the X-ray units may be operated as entirely separate units. Examples of several types of triggers and their applications follow. Some are illustrated in Figure 3.

a. Strain gauge - used in an electronic circuit, usually for studying projectile performance in-bore, where the expansion of the gun tube during projectile travel acts upon the gauge (attached to the tube) to produce the pulse.

b. Break screen - used in an electronic "break" circuit, usually for terminal ballistic studies in which a projectile or fragment breaks a conductive paint line on the paper screen to cause a pulse.

c. Blast pressure switch - used in a "make" circuit, usually at the side of the gun muzzle, where expanding gases rebounding off the base of an exiting projectile press a metal diaphragm against a contact.

d. Photocell pickup - used in a "make" circuit usually at a gun muzzle, where increasing luminosity produced by escaping propellant gases is detected.

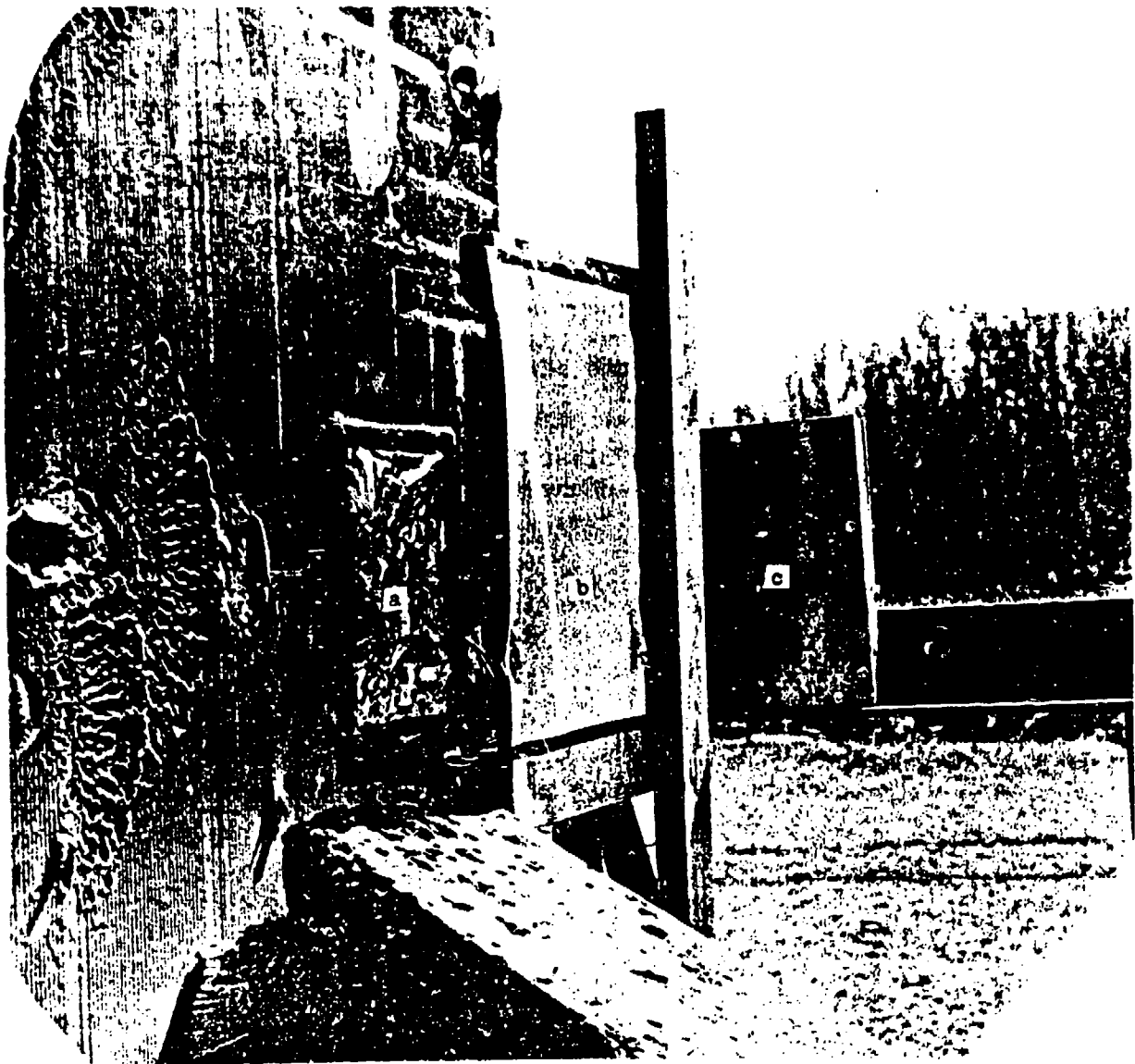


Figure 3. Target plate showing:

- a. Foil "make" trigger on plate
- b. Paper printed circuit "break" trigger in front of plate
- c. Metal cassette at edge of plate

e. Foil "make" trigger - aluminum foil backed by cardboard or plastic which makes a circuit when the metal test object shorts the foil to a metal target plate.

3.2.4 Delay Generator Setting. Set the time delay to pulse the X-ray unit as the test object reaches the desired point of travel in front of the film. When an object such as a projectile is moving through air, the time of arrival at the film after triggering can be calculated from standard charge velocity data. When a projectile or fragment is coming off the back of a target plate, such a calculation cannot usually be made. A time must be estimated and then checked by trial and error. It is often useful to place a thin reference wire in the expected path of the test object to show whether the timing is fast or slow by the presence or absence of the wire on the X-ray film.

3.3 Data Required. Record/obtain the following:

a. Test item.

- (1) Weapon identification
- (2) Projectile identification
- (3) Projectile velocity
- (4) Modifications of projectile to enhance radiographic image
- (5) Target description (if applicable).

b. Equipment setup.

- (1) Number of channels
- (2) Time delay between channels
- (3) Film size, type and containment
- (4) Distance from film to object
- (5) Distance from X-ray tube(s) to object
- (6) Distance of film down range from muzzle or up range from target
- (7) Type and location of triggering device
- (8) Protection to X-ray tube(s)
- (9) Protection for pulser
- (10) X-ray unit used
- (11) Type of intensifying screens
- (12) Photograph of setup.

3.4 Radiography Test Controls. X-ray facilities will be operated according to procedures approved by the RPO and the Radiation Control Committee.

a. All personnel assigned to X-ray operations will wear film badges.

b. Post exposure areas with radiation warning signs in accordance with AR 385-30.1*

c. Observe all range and facility safety regulations throughout the radiographic examination.

d. Qualified X-ray personnel will operate the flash X-ray equipment in accordance with the equipment manuals.

3.5 Operational Checkout. When a new or modified setup is installed, perform an operational checkout to determine the effectiveness of the system. Fire an appropriate, easy-to-use projectile to simulate the actual test item. Once all

sensors are functioning as evidenced by counter times, film may be used to check the overall operation.

4. TEST PROCEDURE FOR RADIOGRAPHIC EXAMINATION.

- a. Prepare the X-ray unit for operation in accordance with the operating manual.
- b. Charge the system to desired kV and use trigger circuits to pulse the system.
- c. Check whether the expected X-ray dose is being produced in front of the tube. Direct reading pocket dosimeters are useful for this purpose. The actual dose at any distance can be calculated from the following inverse square law:

$$\frac{I_1}{I_2} = \frac{d_2^2}{d_1^2}$$

in which I_1 is the measured or known dose at a given distance, d_1 , and I_2 is the dose at another distance, d_2 .

- d. Load all film holders in their proper location at the setup.
- e. Re-set all timers and pre-set all delay generators.
- f. Ensure that air pressures are at proper levels.
- g. Charge the system to proper kV.
- h. Fire the weapon to function the X-ray-triggering circuit according to the particular firing program.

5. DATA REQUIRED. Record/obtain the following:

- a. Date and time of examination
- b. Dosimeter readings
- c. Film number versus round number for each firing.

6. PRESENTATION OF DATA.

- a. Verify that the X-ray film holders contain identification numbers or letters (para 3.2.2d); if they do not, mark the films using a film perforator as soon as they are brought into the viewing room after processing.
- b. Process the film in accordance with film manufacturer's developing procedures. Use freshly prepared chemicals to obtain maximum contrast and density (darkness). These are essential with low energy X-rays for discerning different pieces on the film.
- c. Read the radiograph, and record the factors appropriate to the specific test (App A, para 3). Most information can be obtained by visual inspection. Measurements of projectile attitude or shape may be made by comparing the image with the lead reference markings. High-intensity X-ray film viewers are useful in detecting fine details in films with high photographic densities.

*Superscript numbers correspond to reference numbers in Appendix C.

d. When very accurate film measurements are necessary, allow for image magnification created by the geometry of the setup. Any distances measured on the X-ray film can be mathematically corrected to actual distances by using data obtained in paragraph 3.3.b, 4, and 5, and fiducial markers.

e. X-ray film presentations frequently require more than one piece of film to record an event. A marking system (e.g., grids) must be used to allow precise reconstruction of the film placement on a viewing system. Grid placement will have a tolerance of $\pm 1/32$ of an inch, as a minimum.

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APPENDIX A FLASH RADIOGRAPHIC EQUIPMENT

1. Description. Radiography is one of the most widely used nondestructive test techniques. Flash radiography is a special adaptation which was first used in the United States for studies of shaped charge jets. It differs from conventional industrial radiography in that the X-ray energy is delivered in the form of a pulse of fractional microsecond duration as opposed to the continuous level output of industrial machines.

Basic flash radiographic equipment (fig. 1) consists of a Marx-type generator, charging transformer, triggering circuit and a cold cathode field emission X-ray tube. The Marx generator or pulser is comprised of a bank of capacitors arranged so that they are charged in parallel, then switched through spark gaps to discharge in series. A pressurized dry nitrogen system ensures a constant operating atmosphere for the spark gap discharge. In operation, a trigger pulse is amplified by a transformer to an amplitude sufficient to cause a voltage breakdown across the initial spark gap. The series discharge follows and is impressed across the X-ray tube.

2. Advantages and Limitations. During ballistic testing, it is often necessary to obtain projectile performance data that cannot be obtained by means of high speed cameras. With camera coverage, the location and shape of projectile parts in-bore, at the muzzle, and upon impact with a target usually are obscured by flash, smoke, debris, and other intervening materials. Flash radiographic equipment, on the other hand, can provide views of the more dense projectile parts with little interference from the less dense intervening materials. In this sense, flash radiography may be used to supplement regular photographic coverage. There is an additional advantage, however: the view is a radiograph as well as an outline or shadowgraph of the test object.

Flash radiography has been used in studies of shaped charges, armor-piercing discarding sabot projectiles, defeat of special armor arrangements, and interaction of explosive projectiles with targets, among other applications. Most flash radiographic equipment is limited by relatively low radiation output to a fairly small amount of true radiographic utility where internal parts of items can be viewed. Specially constructed projectile components may occasionally be necessary to permit the viewing of internal parts.

Another limitation of this technique is the fact that X-rays cannot be focused in a practical sense; thus, images must be recorded full scale on large sheets of film. This prevents a rapid movement of film (such as in a movie camera) and limits the number of views or frames in sequence of one dynamic event.

3. Information Generated.

- a. Dynamic behavior of in-bore/out-of-bore projectile or fragment.

<u>Parameter</u>	<u>Uncertainty of Data at One Standard Deviation</u>
Yaw and pitch	± 0.10
Muzzle, striking, and between-plate velocities	$\pm 3\text{m/s}$ ($\pm 10\text{ ft/sec}$)
Velocity exiting plate	$\pm 7.6\text{m/s}$ ($\pm 25\text{ ft/sec}$)
Mass	$\pm 10\%$
Kinetic energy	$\pm 10\%$
Dispersion	$\pm 10\%$
Probability of incapacitation	$\pm 10\%$
Crushup	$\pm 0.25\text{cm}$ ($\pm 0.1\text{ in.}$)

b. Dynamic behavior of a shaped charge.

<u>Parameter</u>	<u>Uncertainty of Data at One Standard Deviation</u>
Jet length	$\pm 0.5\%$
Jet width	$\pm 0.5\%$
Particle velocity	$\pm 1\%$
Particle mass	$\pm 10\%$
Kinetic energy of particle	$\pm 10\%$
Position	$\pm 0.25\text{cm}$ ($\pm 0.1\text{ in.}$)

APPENDIX F
CHECKLIST GUIDE FOR RADIOGRAPHIC EXAMINATION OF BALLISTICS

ITEM	YES	NO	NA
1. All operating personnel briefed about test requirements, special procedures, hazards, and any unusual aspects of the tests			
2. Test item and equipment setup data recorded (para 3.3)			
3. Instrumentation calibrated, properly installed and operational			
4. X-ray tube protected			
5. X-ray dosage checked			
6. Lead identification numbers or letters and lead reference marks positioned in front of film holder or cassette			
7. Film badges worn by all personnel			
8. Exposure areas posted in accordance with AR 385-30			
9. Safety requirements accomplished and all safety regulations posted at the test site			

APPENDIX C
REFERENCES

1. AR 385-30, Safety Color Code Markings and Signs, 15 September 1983.
2. TOP 4-2-805, Projectile Velocity Measurements, 21 September 1982.